Milan Čoh

Integrated biomechanical diagnostic

procedures in athletes' training

Key words**: biomechanic, diagnostics procedures, training**
Ključne riječi: **biomehanika, dijagnostičke procedure, trening**

Original scientific paper

Abstract
The sports results at the current level of development of technology and sport training methodology are a result of a planned, programmed and controlled process of sports training. This is an extremely complex process that has to have predefined goals, resources and training methods. Diagnostics based on new methods has a function of immense importance in the structure of modern sports training. The purpose of diagnostic procedures is gathering of relevant and objective parameters for the preparation of athletes. Biomechanical laboratories operate today based on the principle of integration and synchronization of diagnostic measuring instruments and methods. Interrelated systems enable us to conduct complex analyses of biomotoric capabilities and control of movement structures. Such a strategy of biomechanical research enables us to establish quantity and quality characteristics of the preparation of athletes. Based on data gathered in such a way, the best resources are selected, and a division into cycles and modeling of trainings is conducted. This paper includes some biomechanical diagnostic methods, including kinematics, dynamics, electromyography and isokinetics. All these methods have been successfully implemented in the process of training and diagnostics of athletes who achieved the best international sports results.

Sažetak
Sportski rezultati na današnjom stupnju razvoja tehnologije i metodologije sportske pripreme javljaju se kao produkt planiranog, programiranog i kontroliranog procesa sportskog treninga. To je izuzetno složen proces, koji mora imati u napred definirane ciljeve, sredstva i trenažne metode. U strukturi savremenog sportskog treninga ima diagnostika, koja temelji na novim metodama nesumljivo izuzetno važno funkciju. Smisao diagnostičkih procedura je prikupljanje relevantnih i objektivnih parametara pripreme sportaša. Biomehanički laboratoriji danas djeluju na principu integracije i sinhronizacije diagnostičkih mjerskih instrumenata i metoda. Međusobno povezani sistemi nam omogućuju kompleksn analize biomotoričkih sposobnosti i kontrolu kretnih struktura. Takva strategija biomehaničkog istraživanja nam daje mogučnost utrvđivanja kvantitativnih i kvalitativnih karakteristika pripreme sportaša. Na temelju tako prikupljenih podataka odabiraju se najoptimalnija sredstva, provodi se ciklizacija i modeliranje treninga. U tom radu su predstavljene neke biomehaničke diagnostičke metode, među njima kinematika, dinamika, elektromiografija i izokinetika. Sve ove metode su bile uspješno implementirane u procese treninga i diagnostike sportaša, koji su postigli najviše međunarodne sportske rezultate.

Introduction

The development of modern sport is closely linked to the invention of new technologies and new expert, scientific, research and organisational methods in the training process. Today, a top sport performance can no longer be generated merely through experience, intuition and other random factors. The procedures and decisions related to sports training must be rational and be as efficient as possible. Given the development level of contemporary sport, results are increasingly becoming a product of a programmed and controlled training process. This is a complex process involving predefined goals, means and methods for transforming the athlete. Diagnostics, which is underpinned by new technologies and technologically methodological solutions, plays an extremely important role in today's athletic training (McGinnis, 1999; Bartlett, 1999). The purpose of diagnostic procedures is to establish relevant and maximally objective parameters of the athlete's form at a given time. Without information on biomotor, morphological, physiological, biochemical, psychological and sociological characteristics it is impossible to plan, programme and model the modern training process. The acquired data facilitate the processes of selecting the optimal methods and means, planning cyclical progress and correcting sports preparations. The development of modern diagnostic methods around the world and in Slovenia is intense and connected to the growing number of specialised institutions. These new diagnostic procedures are generally the fruits of high technologies and expertise in biocybernetics, biomechanics, kinesiology, physiology, biochemistry, genetics and other sciences. In Slovenia, the bulk of sports diagnostics is implemented at the Institute of Sport at the Faculty of Sport in Ljubljana. The technological processes are carried out in laboratories which comply with basic international standards for scientific and research activities involving the measurement of athletes. In recent years, the Institute has been closely co-operating with some other faculties within the University of Ljubljana as well as similar institutions abroad so as to further improve the quality of its work.

The sports training process is characterised by a constant interaction between the developing biomotor abilities and the technical preparation of athletes. This is a dynamic relationship which promptly adapts to the stages of the training process and biological development of the athlete (Mero, Komi, Gregor, 1992; Whiting, Zernicke 1998; Weinec, 2007). Since the already automated stereotypes and level of biomotor abilities are subject to change, the training process needs to be monitored, controlled and corrected accordingly. Modern information, biocybernetic and visual technologies are used for resolving the most complex biomechanical issues in the sports training process. This concept of modern diagnostics enables an objective analysis of movement structures as well as the selection and use of the most appropriate training means and methods for the individual modelling of athletic training (Zatsiorsky, 2000). The key objectives of diagnostics in the athletic training process are as follows:

Faculty of Sport, University of Ljubljana, Slovenia

- controlling basic and specific biomotor abilities;
- optimising technical preparations and thus improving competitive results;
- modelling of biomechanical movement structures;
- formulating movement strategies based on kinematic, dynamic and EMG parameters;
- developing sports equipment and apparatuses;
- developing new technologies for monitoring athletes' technical preparation (kinematics, dynamics, electromyography, tensiometry, thermal vision, velocity tests);
- developing software applications for measuring kinematic, kinetic and electromyographic parameters;
- designing measurement protocols and forwarding information to coaches and competitors;
- controlling motor and technical preparedness during intensive preparations for major competitions;
- controlling technical preparedness under competitive conditions;
- optimal controlling of athletes' preparation based on an integral approach to using different technologies and methods; and
- contributing to progress in sport science and the education of coaches and competitors.

The development of modern athletics as the most universal sport discipline has stemmed and will continue to stem from new expert, technological and organisational approaches to sports training and competition processes. The athletic training procedures will have to become highly efficient and rely on the results of interdisciplinary expert, scientific and research work. In athletic disciplines the results depend on a number of factors, among which sport technique plays a key role. By definition, sport technique is a rational and effective execution of simultaneous or consecutive movements guaranteeing an optimal sport result – with respect to the athlete's abilities and characteristics. The method applied in objective research into sport movements is biomechanics which investigates the structure and functions of biological systems using mechanics methods. The objective of biomechanics is to establish the relevant quantitative parameters of a sport technique by means of objective methods and technology so as to define the state of technical preparedness, technique transformation, technique modelling and correction of an athlete's technical preparedness. The movement technique, which in some so-called technical athletic disciplines strongly impacts on the competitive result, can only be developed, controlled and corrected if all essential defining factors are known. The athlete must consider their morphological characteristics and motor and functional abilities and submit to the material biomechanical laws of a specific sport situation. The implementers of the transformation process must have practical knowledge of the athlete's psychosomatic dimensions, especially those which define the referentiality and configuration of the biomechanical area. A top sport result generally means the athlete's one-time, subtle movement creation which is characterised by a number of details related to technical preparation. Their identification, evaluation and elucidation will enable a further improvement of results in elite athletics, notwithstanding the fact that these have already reached the upper limits of human biological and psychological abilities.

The ever tougher competition in today's athletics requires intensive scientific and research work in the fields of the use of biomechanical technologies and methods enabling an optimally objective analysis and evaluation of athletes' movement structures. Yet one should be aware that it is impossible to measure the entire kinematic and dynamic environment and/or its parameters. The physical environment is highly complex and characterised by many interactions between biological systems and mechanical principles.

Integrated biomechanical diagnostic methods in sport training

Sport technique and/or its movement structure units can be optimally studied at the level of the neurological system functions, biochemical characteristics and locomotor system mechanics. Neuromuscular control is the key factor of movement optimisation. Today, different methods are applied in biomechanical measurement of sport movements and the following have the highest informative value: kinematics, dynamics, electromyography (EMG) and isokinetics. Neuromuscular control is the mainstay of human locomotion (Bobbert, Ingen Shenau, 1988). Neuromuscular control processes are related to co-ordination of the execution of individual movements. Measurement of movement structures nowadays involves highly sophisticated and highly reliable methods; however, these must be integrated into a whole. The highest level of neuromuscular control is the motor area of the cerebral cortex. The role of the thalamus is to receive, process and transmit sensory and motor information to the motor cortex (Bobbert, et al. 1988; Enoka, 2003). A lower level of motor control consists of basal ganglia and cerebellum. Muscles play an important role in this chain of movement structure control. Their contractile functions are related to the feedback information from muscle spindles, the Golgi apparatus, and Ruffini and Pacinian corpuscles. The latter function as afferent information and enable movement control based on the position of joints and tension of ligaments, tendons and muscles.

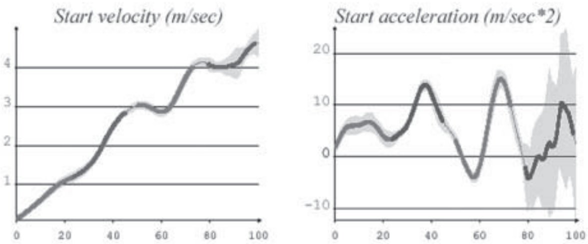
Modern biomotor laboratories function on the principle of the integration and synchronisation of individual measurement systems and methods. Interconnected systems enable complex biomechanical analyses of movement structures and their control. This type of biomechanical research strategy facilitates identification of quantitative and qualitative characteristics and neuromuscular laws in the areas of technique, strength, velocity, co-ordination and other biomotor abilities in athletes' training processes.

The kinematic method

Kinematics is a method for analysing the movements of an athlete's body or individual segments of their body. It enables a quantitative description of movement in space and time using cause/consequence movement quantities. Human movement has been a subject of scientific interest since the ancient past, since the times of Aristotle to Leonardo da Vinci until today. The development of computer and audiovisual technologies enabled tremendous progress in this method. Today, kinematics enables the registration of movements which were previously invisible to our eye and imperceptible to our minds. A major breakthrough in sport biomechanics was the invention of the high-speed camera which can identify movement of a scale corresponding to 1,000 frames per second and more. The next step in the technology of kinematic systems is synchronisation with dynamic systems (force plate) and electromyography. The interconnection of two or more measurement systems facilitates our understanding of biomechanical motor phenomena in cause/consequence dimensions. Besides an objective registration of movement structures, the kinematic method – if underpinned by expert knowledge – enables the modelling and optimisation of the technique in view of an athlete's individual characteristics and abilities.

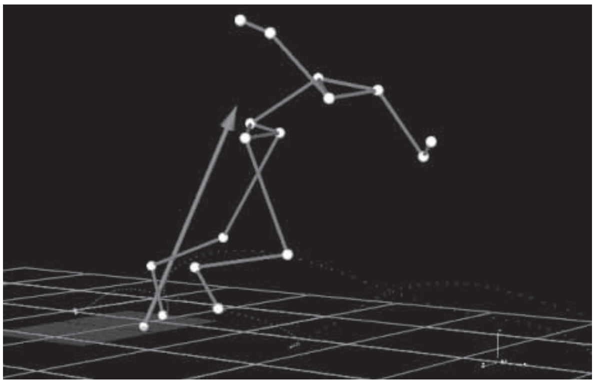
Kinematics is a method based on the recording of movement by high-frequency digital video cameras (100-2000 Hz) in a three-dimensional space. This method is practicable in laboratory or field conditions. The calibration of the space and digitisation of the points that indicate the segments of an athlete's body serve as a basis for establishing the velocity, acceleration, distance and amplitude of the movement of the body's centre of gravity etc. (Figure 1). The real picture is transformed into a digital record using a manual or automated digitisation of the 16-segment model.

Figure 1.
Start velocity: block velocity – start acceleration (rear block – front block), first step, second step



These days infra-red cameras are increasingly being used; they operate on the principle of identifying active landmarks fastened to pre-selected segments of the athlete's body (axes of segments) – Figure 2. The advantage of infra-red kinematic systems lies in the real-time registration of movement, whereas their drawback is that they can only be used indoors, in laboratory conditions.

Figure 2.
The kinematic system BTS smart – sprint start



The dynamic method

Dynamics is a method for diagnosing the forces produced in different movement structures. This method usually requires the use of force platforms to measure forces in vertical (Y), horizontal (X) and lateral (Z) directions. This technology enables measurement of the forces of the take-off in a start, sprint, long-jump, triple jump and high jump. Tensiometry as a method is most frequently used in diagnostics of the level of development of the take-off power/speed strength in laboratory and competition (situational) conditions. Take-off power is diagnosed by using different test batteries. Take-off power in the conditions of concentric strain is measured during a squat jump, using the force platform (Kistler 9287). The subject jumps vertically from a completely fixed position, without swinging their arms and with a knee angle of 140° to 150°. Thus the effect of elastic energy in the muscles and reflex mechanisms is eliminated. Take-off power in the conditions of eccentric-concentric muscle contraction is measured during a counter movement jump, whereby the muscles extend and then immediately contract. The elastic energy produced by the muscles and tendons in the first phase is transferred to the second phase to increase the jump height (Gollhofer, Kyrolainen, 1991; Luhtanen, Komi 1980; Zajac, 1993). The third type of jump in the conditions of eccentric-concentric muscle contraction is a depth jump (also called a drop jump) which is executed from a height of 25 cm to 40 cm. The optimal depth depends on the efficiency of the extensor muscles of the ankle and knee joints.

Table 1 and the measurement protocol (Figure 3) reveal those dynamic and kinematic parameters that generate the jump height. The key parameter is the take-off velocity which depends on the impulse force in the concentric phase, the peak ground reaction force (peak force) and power (W) per 1 kg of body mass. In all vertical jumps, a limiting factor is the time available for the execution of an explosive movement. The force generation time in the concentric phase ranges from 314 ± 6 to 326 ± 17 milliseconds.

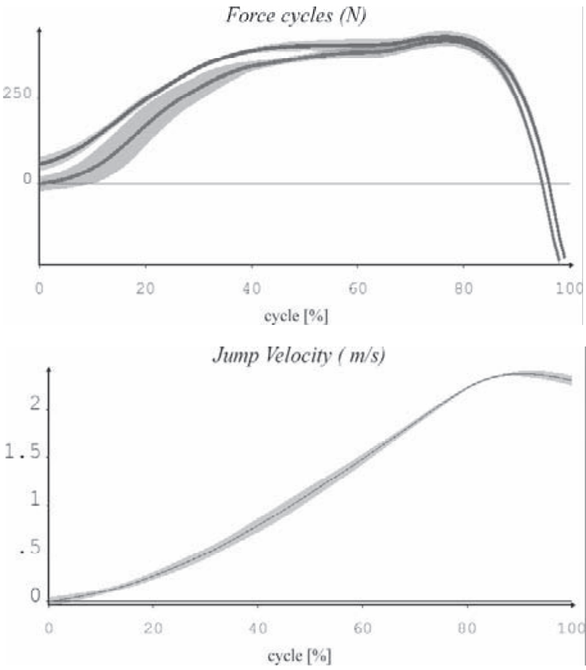
Table 1.
Dynamic and kinematic parameters of the squat jump

TEST	UNIT	A
SQUAT JUMP		
Jump height	cm	45.8 ± 0.5
Concentric time	ms	314 ± 6
Concentric work	J/kg	6.5 ± 0.2
Jump efficiency	cm/J	7.0 ± 0.3
Peak power	W/kg	48.7 ± 1.1
Flight time	ms	572 ± 4
Take-off velocity	$m.s^{-1}$	2.37 ± 0.3
Peak force	N	846 ± 1.4
Generated concentric impulse	Ns	172 ± 3
Hip flexion	deg	84 ± 2
Knee flexion	deg	89 ± 2
Ankle flexion	deg	30 ± 1

Figure 3.
Measurement protocol – squat jump

Some authors (Gollhofer, Kyrolainen, 1991; Bobbert et al., 1987) have demonstrated that squat vertical jumps largely depend on the contractile characteristics of muscles and considerably less on reflex mechanisms and pre-activation. The optimal knee angle ranges from 89° to 90° and the hip angle from 71° to 84°. These angles are important as the take-off action in the initial phase is associated with the action of the hip and trunk joint extensors. The final take-off velocity mainly depends on the knee and ankle joint extensors. Study subject A had an angular velocity of 514 °/s in their hip joint, 771 °/s in their knee joint and 878 °/s in their ankle joint. These angular velocities are slightly higher than those recorded in the research by Bobbert et al. (1987). Last but not least, it was established that, in terms of bilateralism, subject A was deficient in the production of force with their right leg. The force impulse produced by their right leg was 14 Ns less than that produced with their left leg (Figure 4).

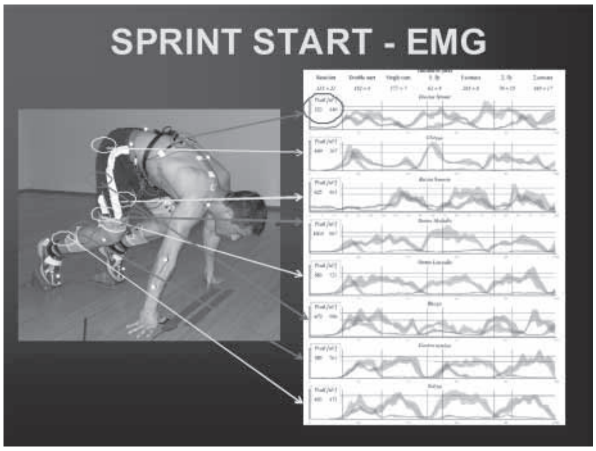
Figure 4.
Measurement protocol for dynamic parameters of the squat jump



The electromyographic method (EMG)

Electromyography (EMG) is a method for establishing the bioelectrical activity of muscles during the execution of specific movement structures. It enables the reception of information about the functioning of strategically important muscle groups. It requires the use of bipolar surface electrodes that send emissions through eight reception channels. Modern telemetric electromyographic systems enable the measurement of EMG activity in situational/field conditions. The 16-channel Smart-BTS telemetry system operates at a frequency of 1000 Hz to 2000 Hz and is used to register bioelectrical activity in some athletic disciplines (sprint, athletic jumps and throws). Surface electrodes are fastened onto the skin above selected muscle groups according to the SENIAM methodology. With a sprint the selected muscle groups are the following: m. soleus, m. gastrocnemius, m. tibialis anterior, m. vastus lateralis, m. rectus femoris, m. biceps femoris and m. gluteus maximus (Figure 5). The EMG measurement results provide important information about the time of activation, scope of activation and intermuscular co-ordination.

Figure 5.
Integrated electromyographic muscle activation (EMG). Block velocity (rear block-front block, first step, second step)



The isokinetic method

Isokinetic systems are used in athletes' training process to measure the muscular strength of individual muscle groups (Figure 6). Moreover, isokinetics is an important diagnostic tool in rehabilitation after an injury in the motor system as it enables objective monitoring of muscular strength and the planning of preventive training programmes for patients. Data delivered by the isokinetic measurement are objective, accurate and repeatable. They are indispensable in the planning of the training process during various stages of an athlete's preparation (Bračič, 2008). One of the basic parameters of the isokinetic protocol is peak torque (PT) expressed in Newton-metres (Nm). This is the basic criterion of muscular strength. As muscular strength correlates highly with body weight, this parameter should be normalised prior to conducting a comparison with other study subjects, namely peak torque should be divided by body weight. As measurement is carried out separately for each segment (limb) a bilateral comparison of muscular strength is also possible (knee extensors, left/right leg).

Figure 6.
Isokinetic test of the knee extensors and flexors

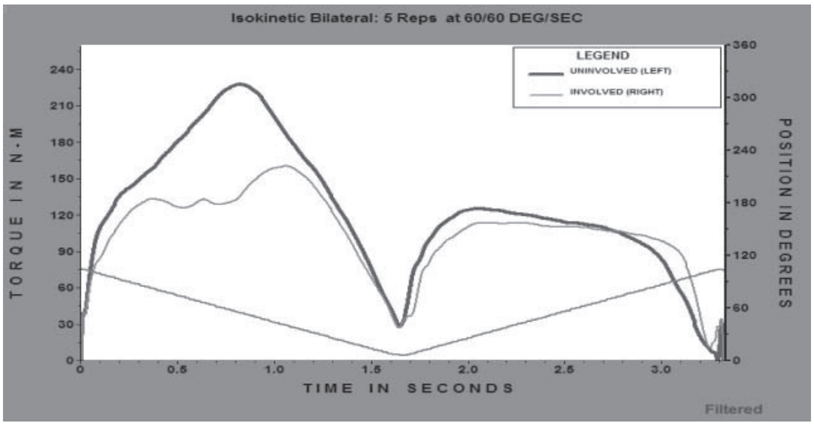


Figure 7.
Protocol for measuring the peak torque of the quadriceps and hamstring in the knee joint at a speed of 60 °/sec.

	UNIT	RIGHT	LEFT
PEAK TORQUE	Nm	160.3	227.6
PEAK TORQUE/BW	%	267.5	379.8
AGON/ANTAG RATIO	%	70.8	55.0

Extremely important information in isokinetic measurements is the estimated ratio between the strength of the agonist and antagonist muscle groups (knee extensors/flexors) – Figure 7. Isokinetics enables measurement of the entire muscle chain of the strategically most important locomotor muscle groups. It also enables identification of the weakest links in the muscle chain. Isokinetics is an indispensable tool for the prevention of sports injuries. A large disproportion in the strength of muscles (m. quadriceps – m. biceps) in the knee joint indicates the high probability of an injury of this segment. Diagnostics of athletes most often includes measurement of the peak torque of the flexor and extensor muscles in the ankle, knee and hip joints. Measurements of the extension and flexion of individual joints are conducted at different velocities. As a rule, velocity ranges from 60 °/sec to 240 °/sec. At a velocity of 60 °/sec, the peak torque of the hamstring reaches 60% of the peak torque of the quadriceps (Osternig et al., 1983). To ensure that isokinetic measurements are maximally correct and objective, the exact protocol, stabilisation and motivation of the subject must be provided.

Figure 8.
Protocol for longitudinal measurement of torque in the ankle flexors and extensors

Repeatability of isokinetic measurements plays an important role in longitudinal monitoring of the isokinetic parameters of agonist and antagonist muscles in individual regions (Figure 8). This approach enables efficient monitoring of the effects of the training process in the area of muscular strength. Timely identification of the status of muscular strength enables the elimination or correction of potential deficiencies in an athlete's training process.

Conclusion

The application of sport science findings and modern diagnostic procedures in the analysis, planning and control of athletes' levels of training has radically improved athletes' achievements in many sports. New measurement technologies enable increasingly accurate programming and monitoring of the training process. It is particularly important that the diagnostic systems are integrated and synchronised. This type of approach brings about results showing quantitative and qualitative characteristics of biomotor abilities which contribute the most to an athlete's performance. Modern training is characterised by rationality, predictability and

		2007				2008		
	60°/SEK	**PF_L**	**PF_D**	**DF_L**	**DF_D**	**PF_L**	**PF_D**	**DF_L**
ANKLE	**PT**	71.5	73	24.7	27.6	82.8	89.8	27.4
	TPT	450	510	500	580	280	220	420
	AG/ANT	34.5	37.8			33.2	30.2	

efficiency. Biomechanical diagnostic methods have strongly influenced sport achievements at the extreme limit of human abilities and will continue to do so even more effectively in the future.

References

Bartlett, R. (1999). Sports Biomechanics-Reducing Injury and Improving Performance. E & FN SPON.

Bobbert, M., Huijing, P., van Ingen Schenau, G. (1987). Drop jumping I. The influence of jumping technique on the biomechanics of jumping. Medicine and Science in Sport and Exercise, 19:332-338.

Bobbert, M., van Ingen Schenau, G. (1988). Coordination in vertical jumping. Journal of Biomechanics, 21:249-262.

Bračič, M. (2008). Uporaba izokinetike v atletskem treningu. Atletika, 57/58, 17-21.

Gollhofer, A., Kyrolainen, H. (1991). Neuromuscular control of the human leg extensor muscles in jump exercises under various stretch-load conditions. International Journal of Sports Medicine, 12, 34-40.

Enoka, R. (2003). Neuromechanics of human movement. Human Kinetics, Champaign, IL.

Luhtanen, P., & Komi, P. (1980). Force-, power- and elasticity-velocity relationship in walking, running and jumping. European Journal of Applied Physiology 44 (3), 79-289.

McGinnis, P. (1999). Biomechanics of Sport and Exercise. Human Kinetics, Champaign, IL.

Mero, A., & Komi, P. (1994). EMG, Force, and Power Analysis of Sprint-Specific Strength Exercises. Journal of Applied Biomechanics, 10 (1), 1-13.

Mero, A., Komi, P., Gregor, R. (1992). Biomechanics of Sprint Running. Sport Medicine 13, 6, 376-392.

Zajac, F. (1993). Muscle Coordination of Movement: A Perspective. Journal of Biomechanics, 26 (1), 109-124

Zatsiorsky, V. (2000). Biomechanics in Sport, Blackwell Science.

Weineck, J. (2007). Optimales Training. Spitta Verlag GmbH &Co

Whiting W., Zernicke, R. (1998). Biomechanics of Musculoskeletal Injury, Human Kinetica, Champaign, IL, 1998.

Winter, D. (2005). Biomechanics and motor control of human movement. John Wiley & Sons, INC.

Submitted: December, 19. 2008.
Accepted: February 15, 2009.

Correspodence to:
Milan Čoh
Faculty of Sport, University of Ljubljana
Gortanova 22, 1000 Ljubljana, Slovenia
Phone: +386 01 520 77 37
E-mail: milan.coh@fsp.uni-lj.si